CORRELATION OF UPPER PENNSYLVANIAN BEDROCK STRATA AT THE PROPOSED LOW-LEVEL RADIOACTIVE WASTE DISPOSAL FACILITY AT THE GEFF ALTERNATIVE SITE, WAYNE COUNTY, ILLINOIS

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EXECUTIVE SUMMARY

The relationship between upper Pennsylvanian strata at the Geff Alternative Site (GAS), Wayne County, and upper Pennsylvanian strata in the northern part of the Illinois Basin is determined by the application of cross-basin sequence stratigraphy and is supported by the palynology of selected coals. Nine marine-terrestrial sequences are differentiated at the GAS. From within these sequences, the Shoal Creek (Carthage) Limestone, Mt. Carmel Sandstone, and Flannigan Coal Members of the Bond Formation, and the Cohn Coal and Shelbyville Coal Members of the Mattoon Formation are correlated from other parts of the basin with lithologic units at the site. The lower part of the Millersville Limestone Member of the Bond Formation and the Merom Sandstone Member of the Mattoon Formation are only tentatively correlated. The top of the Millersville Limestone Member is not recognized at the site and the boundary between the Bond and Mattoon Formations cannot be determined. The strata at the GAS are differentiated into Bond Formation, undifferentiated Bond-Mattoon Formation, and Mattoon Formation.

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PURPOSE

A thorough understanding of stratigraphy and lithology is essential to the location and characterization of any waste disposal site. Information gathered from these studies is critical to the overall siting process because stratigraphic and sedimentologic data is used to evaluate the long-term site stability and extent of interaction between the site and its nearby surroundings. In addition, site specific stratigraphic and lithologic investigations provide a basis for interpretation and placement of local geology within a regional geologic framework. In this report, the stratigraphy of the bedrock was studied to clarify and verify correlations by Battelle Memorial Institute and Hanson Engineers Inc.[1] (1989a, 1991) as part of the site characterization for a proposed low-level radioactive waste disposal facility at the Geff Alternative Site (GAS) in Wayne County, Illinois (Figure 1). Although this work was conducted in close cooperation with site consultants, this report is an independent assessment of the GAS stratigraphy, and therefore is a quality control check on the stratigraphic interpretations and discussions contained in other GAS characterization reports.

[1]Hereafter referred to as BMI & HEI.

METHODOLOGY

In this study, nine test borings were examined and described in detail (G-01, G-08, G-18, G-20, G-22, G-106H, G-107H, G-115G, G-116G) and ten test borings were examined and described in less detail (G-06, G-07, G-10, G-11, G-14, G-15, G-41, G-42, G-111G, G-114E). From these borings, a data base was developed that included the deepest borings on the GAS with an equal, areal distribution of data points. The cores from the test borings were described according to procedures outlined in Technical Procedure 1.1 (Berg and others, 1989). A total of 2,472.7 feet of core were described in detail and 1,903.5 feet were described in less detail. In addition, core descriptions of other test borings on the GAS (BMI & HEI, 1989b, 1991) were used for this study.

The lithologic and stratigraphic units described and differentiated in the test borings are correlated with strata in other parts of the Illinois Basin. Correlation is the demonstration of equivalency of stratigraphic units. Equivalency is demonstrated by several methods, including tracing lateral continuity, lithologic identity, and sequence position (Krumbein and Sloss, 1963). Another method of identifying strata is the application of sequence stratigraphy, or correlation by recognition of equivalent sequences (discussed below).

Correlation of members and beds in middle Pennsylvanian strata in the Illinois Basin generally has depended upon recognition of relatively thick and laterally widespread coals and limestones. In upper Pennsylvanian strata, coals are laterally widespread but thin; thus limestones, such as the Shoal Creek Limestone[2] and Millersville Limestone, are key horizons upon which correlations

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[2]The preferred name for the Shoal Creek Limestone is the Carthage Limestone (Jacobson and others, 1985), but the former will be used in this report to be

of other lithologic units, particularly coal, are dependent. For example, Nance and Treworgy (1981) described the stratigraphic positions of numerous coal beds by estimating the thickness of the interval between the coal and a key limestone bed.

Correlation of units in intervals that lack distinctive key beds is difficult and requires methods other than lithostratigraphic studies. At the GAS, the biostratigraphy of coals was employed to support the lithostratigraphic studies. Coal biostratigraphy is based on the identification of spores (palynology). Coal beds that contain similar types and numbers of spores are considered to be biostratigraphically (time) equivalent. Coals were sampled from test boreholes G-01 (at depths 189.7-190.1, 236.6-237.1, 342.2-342.4, 422.2-423.2, 458.9-459.9, 509.0-510.8, 518.6-519.5 ft) and G-107H (at depths of 40.4-41.0 and 183.0-183.2 ft) for palynological analysis. These samples were analyzed by Dr. Russel Peppers, palynologist at the Illinois State Geological Survey, according to procedures outlined in Technical Procedure 1.7 (Berg and others, 1990).

PRELIMINARY STRATIGRAPHIC CORRELATIONS

Introduction

The initial draft report on the bedrock geology at the GAS (BMI & HEI, 1989a) regionally identified units in borings G-01 and G-08 with the following units, in ascending order: Shoal Creek Limestone, Mt. Carmel Sandstone, Flannigan Coal, and Reel Limestone. The Millersville Limestone, Merom Sandstone, and the Opdyke Coal also were identified in these two borings and correlated in most of the shallow borings. The units were correlated using the methods of

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consistent with the terminology used in other GAS reports.

lithologic identity and sequence position. The revised draft report (BMI & HEI, 1991) regionally identified only the Shoal Creek Limestone.

Discussion

The identification of both the Shoal Creek Limestone and the Millersville Limestone at the GAS is critical because these units are key marker beds in the Illinois Basin. According to the stratigraphic code, a key bed is a thin bed of distinctive lithology that is widely distributed (North American Commission on Stratigraphic Nomenclature, 1983) and often is used for a formation boundary or is a datum upon which other correlations are based.

The base of the Shoal Creek Limestone is the contact between the Modesto Formation and the overlying Bond Formation (Kosanke and others, 1960). The limestone identified as the Shoal Creek Limestone at the GAS (BMI & HEI, 1989a, 1991) is supported by this study. The Shoal Creek is a widespread unit and is correlated by lithology, sequence position, and by sequence stratigraphy (discussed in detail below).

The top of the Millersville Limestone is the contact between the Bond and the Mattoon Formations (Kosanke and others, 1960). In the initial draft report (BMI & HEI, 1989a), a sandstone (the "first sandstone" in BMI & HEI, 1991) just above "Millersville" limestone at the GAS was correlated with the Merom Sandstone Member of the Mattoon Formation. The basis of this correlation is that near the town of Merom on the Indiana-Illinois boundary, the Merom Sandstone Member overlies the Livingston Limestone Member--the stratigraphic equivalent of the Millersville (Weller, Henbest, and Dunbar, 1942; Taylor and Cady, 1944; Wanless, 1955; Clegg, 1959). The present study, however, indicates that the limestone, identified as "Millersville" in the initial draft report (BMI & HEI, 1989a) and as the "calcareous claystone/mudstone and/or limestone" in the revised draft report (BMI & HEI, 1991), is not equivalent to the Millersville Limestone. This conclusion is based on the following observations:

1) Middle and upper Pennsylvanian strata are characterized by cyclic sequences, or cyclothems. The position of certain units, relative to each other, within these sequences is consistent. When a coal, marine limestone, and an "underclay" claystone/mudstone are present within a single sequence, the ascending order of these units is "underclay", coal, and marine limestone. Units of marine origin succeed units of terrestrial origin. The "calcareous claystone/mudstone and/or limestone" ("Millersville" limestone of BMI & HEI, 1989a) underlies a coal (the "second coal" of BMI & HEI, 1991) in many of the boreholes at the GAS (G-01, G-06, G-07, G-08, G-11, G-14, G-15, G-18, G-20, G-22, G-41, G-107H). The position of the "calcareous claystone/mudstone and/or limestone" suggests that it is an "underclay" unit. According to Nance and Treworgy (1981) and Russel Peppers (personal communication, 1990), the actual Millersville (Livingston) Limestone overlies a coal, contrary to the sequence at the GAS.

2) The stratigraphic position of the "Millersville" limestone in the cyclothem and its physical characteristics at the GAS (nodular form, absence of fossils, micrite-domination, argillaceous content, and diffuse contacts) indicate that the unit is of a pedologic origin. Weller (1931) and Wanless (1939) referred to similar limestones as "fresh-water limestones." The Millersville Limestone in the northern part of the basin contains a diverse marine fossils (Worthen, 1875; Weller, Henbest, and Dunbar, 1942; Payne and Cady, 1944; Ostrom, 1956; Gilliam and Schram, 1975; Wanless, 1975) and has been interpreted as a phylloid algal bank deposit (Payne and Cady, 1944; Welch, 1975; Giffin, 1978).

Neither marine fossils nor phylloid algae were identified in the "Millersville" core samples at the GAS. Clearly, the "Millersville" limestone at the GAS and the Millersville Limestone Member of the Bond Formation in the northern part of the basin are different limestones that were deposited in different depositional environments and occur in different positions in the cyclothem.

3) Numerous reports have documented that the Millersville Limestone pinches out in the southern part of the basin. Taylor and Cady (1944) mapped the limestone only to Effingham County (7N-8N township boundary) and noted that it thinned to the south. DuBois (1951) mapped it only as far south as Effingham County. Lowenstam (1951) recognized scattered lenses of limestone in northern Clay County as questionable Millersville Limestone. Williams and Rolley (1955) mapped the subsurface strata of Jasper County and noted that the limestone pinched out southward. Potter (1956), in his subsurface study of Crawford County, only mapped it in the northern part. A north-south cross-section by Nance and Treworgy (1981) shows the Millersville Limestone pinching out in west-central Effingham County.

A few reports suggested that the Millersville Limestone is present in Wayne County. DuBois and Siever (1955) included the Millersville Limestone on a generalized stratigraphic column of the Pennsylvanian strata in Wayne County, but neither discussed nor mentioned the limestone in their text. Sims, Payne, and Cady (1944) studied key Pennsylvanian beds in the subsurface of Wayne County and alluded to the Millersville Limestone, but did not definitely recognize it. The geologic map of Illinois (Willman and others, 1967) suggests that the Millersville Limestone is present in the southern part of basin. On the map, the boundary between the Bond and Mattoon Formations is a closed circle and is in the southern half of the basin; thus it appears that the limestone crops out south of Wayne County and therefore could be present in the subsurface at the GAS. This portion of the map is unfortunately misleading and contradicts the aforementioned reports that concluded that the Millersville thinned southward. The location of the contact on the state map appears to be based on an undated isopach map of the Mattoon Formation by K. E. Clegg (see Figure P-16, Hopkins and Simon, 1975). Clegg apparently used some other, unknown lithologic unit to extrapolate a lower boundary for the Mattoon Formation.

Standard methods of lithostratigraphic correlation do not work for the bedrock strata at the GAS. The lateral continuity of the lithologic units cannot be continuously physically traced because the bedrock is largely covered by glacial deposits. The units cannot be correlated by lithologic identity alone because none of the units are unique. Sequence position cannot be used without the identification of key beds, such as the Millersville Limestone Member. However, correlation of the bedrock strata at the GAS is achievable through the application of sequence stratigraphy, or correlation by recognition of equivalent sequences.

SEQUENCE STRATIGRAPHY

Wanless (1956) introduced a stratigraphic classification of the Illinois Pennsylvanian System based on stratigraphic sequences. These sequences previously had been designated as cyclothems and consisted of terrestrial-marine sequences (Wanless and Weller, 1932). This classification, however, was rejected by Kosanke and others (1960) because of the difficulty in mapping basal sandstones and variations in the cyclothem sequence. They replaced cyclothemic formations with much thicker, key bed-bounded formations, such as the Bond Formation.

Weibel (1988) and Weibel and others (1989) showed that modified cyclothems are mappable lithostratigraphic units and are useful for correlation. The cyclothem was modified by placing the base of the cyclothem at the top of the coal or at the bottom of the lowest marine unit, resulting in a marine-terrestrial sequence. This greatly simplified boundary recognition because the terrestrial to marine transition is in a relatively thin portion of the sequence and is characteristically marked by abrupt lithologic change. In addition, coal and marine units are identifiable at the surface and on many geophysical logs.

A similar modified cyclothem is applicable for correlation of the cyclic upper Pennsylvanian strata at the GAS. The reports of Weibel (1988) and Weibel and others (1989) were based on both outcrop and subsurface data. This study, however, is almost entirely based upon subsurface data and lacks the data of outcrop study. The base of the modified cyclothem for this study is placed at the top of the coal or at the bottom of the lowest, regionally widespread marine unit. The modified cyclothem, therefore, consists of an ascending sequence of marine, transitional marine to terrestrial, and terrestrial strata. Transitional terrestrial to marine strata locally may be present at the top of the cyclothem.

SEQUENCES AT THE GEFF ALTERNATE SITE

Nine cyclothems are differentiated within the approximately 600 ft of bedrock strata at the GAS. Cyclothem nomenclature consists of an uppercase letter indicating formation(s) (B = Bond, M = Mattoon, and BM = Bond-Mattoon undifferentiated) and a number, indicating position within the formation (1 = lowest).

Rocks below cyclothem B1 (from 576.8 to 582.3 ft in depth in borehole G-01 and 587.3 to 602.5 ft in depth in borehole G-08) were not studied in detail.

These strata are the upper part of a cyclothem and consist of the terrestrial portion overlain by a thick transitional terrestrial to marine portion (Figure 2).

Cyclothem B1

Cyclothem B1 is 58.2 ft thick in borehole G-01 (from 518.6 to 576.8 ft in depth) and 60.6 ft in borehole G-08 (from 526.7 to 587.3 ft in depth). In ascending order, the cyclothem consists of black shale, limestone, gray shale, interbedded shale, siltstone and sandstone, mudstone, and coal (Figure 2). The marine portion of the cyclothem consists of the black shale and the limestone. The black shale has the fissility (sheet-like) characteristic of Pennsylvanian black shales in the Illinois Basin that often overlay coals (Wanless and Weller, 1932). Generally, these shales range from being sparsely to abundantly fossiliferous and contain a restricted marine fossil fauna. Macroscopic study indicates that the rock is a phylloid algal limestone. The overlying gray shale and the interbedded shale, siltstone, and shale are the transitional marine to terrestrial portion. The lower part of the gray shale is calcareous and contains marine fossil fragments and a thin limestone interbed. The upper part of the shale is noncalcareous and lacks fossils, indicating the change in deposition from wholly marine to coastal/deltaic environments. The terrestrial portion consists of a mudstone and a coal at the top of the cyclothem.

Cyclothem B2

Cyclothem B2 consists of a thin sequence of dark gray shale, claystone, and coal, in ascending order (Figure 2). The cyclothem is only 9.6 ft thick (from 509.0 to 518.6 ft in depth) in borehole G-01 and only 9.9 ft thick (516.8 to

526.7 ft in depth) in borehole G-08. The basal marine portion of this cyclothem is less than one foot thick and ranges from dark gray to black shale. The rest of the gray shale is the transitional marine to terrestrial portion and the claystone and coal at the top are the terrestrial portion.

Cyclothem B3

Cyclothem B3 is 50.1 ft thick in borehole G-01 (from 458.9 to 509.0 ft in depth) and 54.5 ft thick in borehole G-08 (from 462.3 to 516.8 ft in depth). It consists of a basal dark gray shale, a thick clastic interval consisting of siltstone, sandstone, and shale, and is overlain by mudstone and coal at the top (Figure 2). The base of the dark gray shale contains the thin (< 1 ft), fossiliferous, marine portion of the cyclothem. The thick clastic interval is the transitional marine to terrestrial portion and the mudstone and coal are the terrestrial portion.

Cyclothem B4

Cyclothem B4 is 36.7 ft thick in borehole G-01 (from 422.2 to 458.9 ft in depth) and 34.3 ft thick in borehole G-08 (from 428.0 to 462.3 ft in depth). It consists of an ascending sequence of very dark gray, fossiliferous shale, gray shale, claystone, and coal at the top (Figure 3). The basal, very dark gray shale is the marine portion; the gray shale is the transitional marine to terrestrial portion; and the claystone and coal are the terrestrial portion.

Cyclothem BM1

Cyclothem BM1 is 80.0 ft thick in borehole G-01 (from 342.2 to 422.2 ft in depth) and 80.2 ft thick in borehole G-08 (from 347.8 to 428.0 ft in depth) and is composed of many units (Figure 3). The basal marine portion consists of a thin black shale and the overlying thin, calcareous mudstone. The succeeding gray shale, interbedded shale and siltstone, shale, sandstone, and shale are the transitional marine to terrestrial portion of the cyclothem. The uppermost units, a claystone, a lower coal, a shale, interbedded shale and siltstone, a shale, and an upper coal, comprise the terrestrial portion.

Cyclothem M1

The lowest cyclothem of the Mattoon Formation at the GAS is cyclothem M1. It is 105.6 ft thick in borehole G-01 (from 236.6 to 342.2 ft in depth) and is 93.3 ft thick in borehole G-08 (from 254.5 to 347.8 ft in depth). In addition, the cyclothem was partially penetrated in borehole G-07 (from 233.1 to 243.4 ft in depth) and borehole G-11 (from 274.6 to 283.4 ft in depth). In this cyclothem, the basal marine portion consists of thin, fossiliferous limestone and shale (Figure 4). The succeeding transitional marine to terrestrial portion is relatively thick and consists of an ascending sequence of dark gray shale, shale, interbedded siltstone and sandstone, claystone, and interbedded black and dark gray shale. The mudstone and coal at the top of the cyclothem are the terrestrial portion of the cyclothem.

Cyclothem M2

Cyclothem M2 is 46.9 ft thick in borehole G-01 (from 189.7 to 236.6 ft in depth), 44.4 ft thick in borehole G-07 (from 188.7 to 233.1 ft in depth), 53.0 ft thick in borehole G-08 (from 201.5 to 254.5 ft in depth), and 47.6 ft thick in borehole G-11 (from 227.0 to 274.6 ft in depth). The average thickness is 48.0 ft. The cyclothem was partially penetrated in boreholes G-06, G-14, G-15, G-18, G-20, G-22, G-41, G-106H, and G-107H. The marine portion of this cyclothem is only recognized in borehole G-08 where it consists of a thin, fossiliferous black shale. The basal unit in boreholes G-01, G-07, and G-11 consists of a gray to dark gray shale. The succeeding beds in all four boreholes are the transitional marine to terrestrial portion. This portion (Figure 4) consists of interbedded and alternating shale, siltstone, and sandstone beds, including the "second sandstone" of BMI & HEI (1991). The terrestrial portion is interbedded limestone and calcareous shale with coal at the top (equivalent to the "calcareous claystone/mudstone and/or limestone" and the "second coal" of the BMI & HEI, 1991).

Cyclothem M3

Cyclothem M3 (Figure 5) is the thickest cyclothem in the GAS study area and was completely penetrated in thirteen boreholes at the GAS (Table 1). The cyclothem ranges in thickness from 128.5 ft to 154.9 ft; the average is 141.9 ft. The cyclothem was partially penetrated in boreholes G-03, G-10, G-12, G-13, G-16, G-17, G-19, G-21, G-23, G-42, G-43, G-44, G-101G, G-102G, G-103G, G-108G, G-110G, G-111G, G-112G, G-113E, G-114E, G-115G, G-116G, G-126G, G-127G, G-128G, G-129G, G-130G, G-131G, and Geff-1. The marine portion (equal to the "calcareous claystone/mudstone" of BMI & HEI, 1991) is present only in boreholes G-01, G-07, G-15, G-18, and G-107H; in boreholes G-15, G-18, and G-107H, it consists of black shale overlain by calcareous dark gray shale; in boreholes G-01 and G-07, it consists only of black shale. A thin gray shale is the basal unit of the transitional marine to terrestrial portion in boreholes G-11, G-18, and G-107H. In the other GAS boreholes, the marine strata probably were eroded prior to deposition of the thick sandstone unit at the base of cyclothem M3, which often includes a basal conglomeratic sandstone ("basal conglomerate" and "first sandstone" of BMI & HEI, 1991). The thick sandstone and the overlying siltstone and shale/mudstone/claystone (lower part of the "lower claystone and mudstone unit" of BMI & HEI, 1991) occur in all boreholes and also are part of the transitional marine to terrestrial portion. The terrestrial portion consists of the claystone and coal at the top (the lower part of the "lower claystone and mudstone unit" and "first coal") of BMI & HEI, 1991).

Cyclothem M4

The thickness of cyclothem M4, the uppermost cyclothem at the GAS, ranges from 0.6 ft in borehole G-01 to 102.0 ft in borehole G-101G (Table 2). Only the lower portion of the cyclothem is present at the GAS (Figure 6). The upper portion of this cyclothem has been truncated by post-Pennsylvanian erosion. The marine portion is the basal, fossiliferous mudstone which contains thin, discontinuous limestone beds at the GAS (equals the "calcareous claystone and mudstone and/or limestone" of BMI & HEI, 1991). The overlying claystone/mudstone (the "upper claystone and mudstone unit" of BMI & HEI, 1991) is in the transitional marine to terrestrial portion (Figure 6). The entire terrestrial portion is absent.

CORRELATIONS

Two regional cross-sections (Plates 1, 2) were developed for this study (Figure 7). The north-south (Coles County to Wayne County) cross-section (Plate 1) was constructed to determine the boundary between the Mattoon and Bond Formations. The City of Charleston well (hereafter referred to as the Charleston core) was selected as the northernmost data point because it is a continuous core consisting of strata from below the Shoal Creek Limestone to above the Millersville Limestone. A condensed version of this cross-section is shown in Figure 8. The southwest-northeast (Jefferson County to Wayne County) cross-section (Plate 2) was constructed to determine the relationship of coals in the upper part of borehole G-08 to coals in a core (Phillips No. 1) drilled near the outcrops of the Opdyke and Belle Rive Coals in Jefferson County. The sequences described above are correlated on these cross sections. Each sequence is not necessarily differentiated on each geophysical log used because of either local geologic conditions or differences in log resolution. In some cases, these correlations were extrapolated over these wells. Biostratigraphic correlations of selected coal beds (Figure 8) are based on palynology (Russel Peppers, personal communication, 1990).

Cyclothems B1 and B2

Cyclothems B1 and B2 at the GAS are equivalent to the strata from 700 to 738 ft in depth in the Charleston core in Coles County (Plate 1, Figure 8).

Cyclothem B1 is equivalent to the upper part of the Shoal Creek cyclothem of Wanless (1931) and the lower part of the Sorento cyclothem of Simon (1946). The marine portion of the cyclothem consists of an unnamed black shale and the Shoal Creek Limestone (Figure 2). Ball (1952) reported pelecypods, fish fragments, and conodonts from outcrops of this shale in the Carlinville Quadrangle, Macoupin County. The Shoal Creek Limestone is one of the most widespread Pennsylvanian limestones in the basin (Wanless, 1955). This limestone contains abundant marine invertebrate fossils (Ball, 1952). The contact between the black shale and the Shoal Creek Limestone is the datum on the cross-sections (Plates 1, 2).

BMI & HEI (1989a, 1991) identified the Mt. Carmel Sandstone as the sandstone within cyclothem B1, which occurs at depths of 528.3 to 535.0 ft in borehole G-01 and from 535.3 to 550.0 ft in borehole G-08 (Figure 2), respectively. This study supports this correlation. The coal at the top of cyclothem B1 is tentatively correlated with an unnamed coal below the Sorento Limestone, which crops out to the northwest in Bond County (Simon, 1946).

The basal marine portion of cyclothem B2 is black shale and is tentatively correlated to the black shale beneath the Sorento Limestone (and above the previously mentioned unnamed coal) in Bond County. Based on palynologic biostratigraphy, the coal at the top of cyclothem B2 is tentatively correlated with the Flannigan Coal (Figures ,), which crops out in Hamilton County. Hopkins and Simon (1975) and Nance and Treworgy (1981) correlated the Flannigan with the Flat Creek Coal of Bond County.

Cyclothem B3

Cyclothem B3 correlates in the Charleston core with the strata from 662 to 700 ft in depth (Plate 1, Figure 8). The basal marine portion, a black shale, correlates with the black shale that underlies the Reel Limestone in Wabash County. Palynology of this coal at the top of this cyclothem supports the correlation of the sequence (Figure 8). The Reel Limestone is not present in borehole G-08. The preliminary correlation of the Reel in the initial draft report (BMI & HEI, 1989a) was incorrect; however, this correlation is not in the revised draft report (BMI & HEI, 1991).

Cyclothem B4

Cyclothem B4 correlates with the strata in the Charleston core from 562 to 662 ft in depth (Plate 1, Figure 8). The coal at the top of the cyclothem may be equivalent to the Friendsville Coal, but this has not been verified by palynology. Nance and Treworgy (1981) correlated the Friendsville with the Bristol Hill Coal and suggested that the coal is stratigraphically just below the Millersville Limestone. Russel Peppers (personal communication, 1990), on the basis of palynology studies, suggests that the Friendsville underlies a limestone equivalent to the Millersville.

Cyclothem BM1

Cyclothem BM1 is equivalent to the strata in the Charleston core from 516 to 562 ft in depth (Plate 1, Figure 8). This correlation also is based upon palynological study of the coal at the top of the cyclothem (equivalent to the Cohn Coal in Clark County). The contact between the Bond and Mattoon Formations is the top of the Millersville Limestone (Kosanke and others, 1960) which is within cyclothem BM1 in the Charleston core at a depth of 528 ft. This contact is traceable southward to the southern edge of Jasper County (Plate 1). Farther south, the Millersville Limestone is not recognizable on geophysical logs and the Bond-Mattoon Formation contact cannot be traced.

A calcareous mudstone, at a depth of 416.3 to 417.4 ft in borehole G-01 and a depth of 423.9 to 425.9 ft in borehole G-08, is a possible, partial stratigraphic equivalent of the Millersville Limestone. The mudstone may be equivalent to only the lower half of the Millersville Limestone, but more study and additional data are required to support this tenuous correlation. Differentiation of the formation boundary still may not be possible even if future study substantiates this correlation, because the boundary is at the top of the limestone.

The bottom of the stratum overlying the Millersville Limestone, a greenish gray, calcareous mudstone/claystone in the Charleston core, also represents the contact between the Bond and Mattoon Formations. This unit could be used as the lower boundary of the Mattoon Formation, if it were recognizable beyond the extent of the Millersville Limestone. Since it is not a unique lithologic unit and is not readily recognizable on geophysical logs, this mudstone/claystone is not usable as a substitute boundary bed with the available subsurface data.

In this study, the Merom Sandstone Member is tentatively correlated with the sandstone and interbedded sandstone and shale at 354.3 to 368.4 ft in depth in borehole G-01 and at 368.0 to 374.4 ft in depth in borehole G-08 (Figure 3). The correlation depends upon the tenuous, partial correlation of the Millersville Limestone with the calcareous mudstone at the GAS (see cyclothem BM1 correlations above). In addition, the Merom Sandstone at its type locality overlies the Millersville Limestone, but at the GAS, the possible Merom equivalent is separated from the possible Millersville Limestone equivalent by about 50 ft of strata. The palynology of the coal at the top of the sequence was used to correlate the boundary between cyclothems BM1 and M1 (Figure 8).

Cyclothems M1 and M2

Cyclothems M1 and M2 at the GAS are equivalent to the strata in the Charleston core from 484 to 516 ft in depth (Plate 1, Figure 8). Correlation of these two cyclothems separately is not possible at this time. The palynology of the coal in the middle of this interval in the Charleston core indicates that it is equivalent to either the Belle Rive Coal or the Opdyke Coal, both of which crop out in Jefferson County, southwest of Wayne County. The palynology of the coal at the top of cyclothem M1 at the GAS, however, is different from either the Opdyke or the Bell Rive, suggesting that the coal at the GAS may be slightly younger or older than either coal. This is supported in part by the southwest-northeast cross-section (Plate 2) that indicates that coal at the top of cyclothem M1 is at a stratigraphic position close to either the Belle Rive or the Opdyke.

The interbedded limestone and calcareous shale near the top of cyclothem M2 is the "underclay" limestone under the coal (at the top of the cyclothem), and is equivalent to strata just below 484 ft in the Charleston core. The coal at the top of this cyclothem is probably equivalent, based on palynology (Figure 8), to the Shelbyville Coal in Shelby County. The Shelbyville is not present in the Charleston core.

Cyclothems M3 and M4

Cyclothems M3 and M4, along with the Omega cyclothem (see discussion below), are equivalent to the strata in the Charleston core from 303 to 484 ft in depth (Plate 1, Figure 8). These cyclothems cannot be differentiated in the Charleston core. The thick sandstone at or near the base of cyclothem M3 at the GAS ("first sandstone" of BMI & HEI, 1991) was initially correlated with the Merom Sandstone (BMI & HEI, 1989a), but is not in the revised draft report. This study indicates that the Merom tentatively correlates with the clastic unit in the middle of cyclothem BM1. The Merom Sandstone is not present in the Charleston core. The coal at the top of cyclothem M3 has not been identified.

DISCUSSION

The youngest bedrock strata at the GAS cannot be correlated with strata in the Charleston core because the boundary between cyclothems M3 and M4 has not been recognized in the Charleston core. However, the Omega cyclothem of Weibel (1988) and Weibel and others (1989), although not present at the GAS, is projected to overlie cyclothem M4. A limestone, exposed in an abandoned quarry just north of Fairfield (N 1/2, SW 1/4, SW 1/4, section 30, T.1 S., R. 8 E.) and east of the GAS, overlies a coal that has been palynologically correlated with the Calhoun Coal in Richland County (Russel Peppers, personal communication, 1990). The Calhoun is overlain by the Bonpas Limestone, which is probably age equivalent to the Omega Limestone (Weller, Henbest, and Dunbar, 1942; Weibel and others, 1989). The vertical distance between the Omega Limestone equivalent at the Fairfield quarry and the underlying Shoal Creek Limestone (using the structure map of DuBois and Siever, 1955) is approximately equivalent to the vertical distance between the Shoal Creek Limestone and a level just above the top of bedrock at borehole G-08. This correlation is supported by extrapolations on the north-south cross-section (Plate 1), which indicate the stratigraphic position of the Omega Limestone, the basal unit of the cyclothem, is above the top of bedrock at the GAS. Strata above the Omega cyclothem have been differentiated into cyclothems by Weibel (1988) and Weibel and others (1989), and, although not directly relevant to this study, they are identified on the north-south cross section (Plate 1).

The boundary between the Bond and Mattoon Formations cannot be differentiated at the GAS because the top of the Millersville Limestone Member is not recognizable. The strata, however, are differentiated into Bond Formation, undifferentiated Bond-Mattoon Formation, and Mattoon Formation (BMI

& HEI, 1991). The top of the Bond Formation is at 422.2 ft in depth in borehole G-01 and at 428.0 ft in depth in borehole G-08. The bottom of the Mattoon Formation is at 342.2 ft in depth in borehole G-01 and at 347.8 ft in depth in borehole G-08. The strata between the top of the Bond Formation and the bottom of the Mattoon Formation comprise the undifferentiated Bond-Mattoon Formation and consists of cyclothem BM1. The basal, marine strata of cyclothem BM1 at the GAS are equivalent to the black shale underlying the Millersville Limestone in the Charleston core and probably are within the Bond Formation. The uppermost strata of cyclothem BM1, the terrestrial portion, probably are within the Mattoon Formation.

CONCLUSIONS

The stratigraphic conclusions of this study resulted from the interaction of contractor geologists and the Illinois State Geological Survey. A ready and willing exchange of information among all geologists involved on the project was an important factor in the resolution of the bedrock stratigraphy at the GAS. The results of this study are:

1) The relationship between upper Pennsylvanian strata at the GAS and strata in the northern part of the Illinois Basin is determined by the application of sequence stratigraphy and is supported by the palynology of selected coals. Nine sequences are differentiated at the GAS; each sequence is composed of marine strata overlain by terrestrial strata.
2) The correlations of the Shoal Creek Limestone and the Mt. Carmel Sandstone in the reports (BMI & HEI, 1989a, 1991) are supported by this study. The preliminary correlations of the Flannigan Coal, Reel Limestone, and Millersville Limestone Members of the Bond Formation and the Merom

Sandstone and Opdyke Coal Members of the Mattoon Formation (BMI & HEI, 1989a) are not in the revised draft report (BMI & HEI, 1991). This study substantiates correlations that are in the latter report. The Flannigan Coal Member of the Bond Formation and the Cohn Coal and Shelbyville Coal Members of the Mattoon Formation have stratigraphic equivalents at the GAS. The Merom Sandstone and the lower part of the Millersville Limestone are tentatively correlated with lithologic units at the GAS.

3) The boundary between the Bond and Mattoon Formations cannot be differentiated because the top of the Millersville Limestone Member is not recognizable at the GAS. The strata are differentiated into Bond Formation, undifferentiated Bond-Mattoon Formation, and Mattoon Formation.

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BORING	DEPTHS	THICKNESS
G-01	36.0-189.7	153.7
G-06	81.2-226.5	145.3
G-07	45.8-188.7	142.9
G-08	60.5-201.5	141.0
G-11	79.3-227.0	147.7
G-14	72.3-212.4	140.1
G-15	65.5-194.0	128.5
G-18	47.7-176.7	129.0
G-20	98.4-242.6	144.2
G-22	114.0-244.5	130.5
G-41	69.5-224.4	154.9
G-106H	88.6-233.2	144.6
G-107H	40.4-183.0	142.6

Table 1. Depth intervals and thickness of cyclothem M3 at the GAS. Measurements in feet.

BORING	TOP OF BEDROCK	BASE OF CYCLOTHEM	THICKNESS
G-01	35.5	36.1	0.6
G-03	11.4	45.3	33.9
G-06	15.0	81.2	66.2
G-07	25.0	45.8	20.8
G-08	17.7	60.5	42.8
G-10	20.0	78.5	58.5
G-11	13.5	79.3	65.8
G-12	11.0	77.8	66.4
G-13	15.0	77.5	62.5
G-14	9.5	72.3	62.8
G-15	21.0	66.1	45.1
G-16	9.5	72.5	63.0
G-17	18.0	66.0	48.0
G-18	15.9	47.7	31.8
G-19	14.3	47.9	33.6
G-20	14.8	98.4	83.6
G-21	14.5	98.5	84.0
G-22	12.5	114.2	101.7
G-23	11.4	112.8	101.4
G-41	15.3	69.5	54.2
G-42	10.0	68.6	58.6
G-43	10.0	69.2	59.2
G-44	10.0	68.4	58.4

Table 2. Depth of top of bedrock, depth of cyclothem base, and cyclothem thickness of cyclothem M4 at the GAS. The upper portion of the cyclothem is absent because of post-Pennsylvanian erosion. Measurements in feet.

BORING	TOP OF BEDROCK	BASE OF CYCLOTHEM	THICKNESS
G-101G	9.0	111.0	102.0
G-102G	10.0	82.0	72.0
G-103G	10.0	77.0	67.0
G-106H	20.0	88.6	68.6
G-107H	20.0	40.4	20.4
G-108G	10.0	42.0	32.0
G-110G	18.4	83.1	64.7
G-111G	20.0	61.3	41.3
G-112G	20.0	52.6	32.6
G-113E	15.5	57.7	42.2
G-114E	19.8	84.3	64.5
G-115G	20.3	87.9	67.6
G-116G	20.8	67.6	46.8
G-126G	7.0	78.0	71.0
G-127G	21.0	54.5	33.5
G-128G	37.5	58.0	20.5
G-131G	17.0	57.0	30.0
GEFF-1	8.0	78.5	70.5

Table 2 continued.

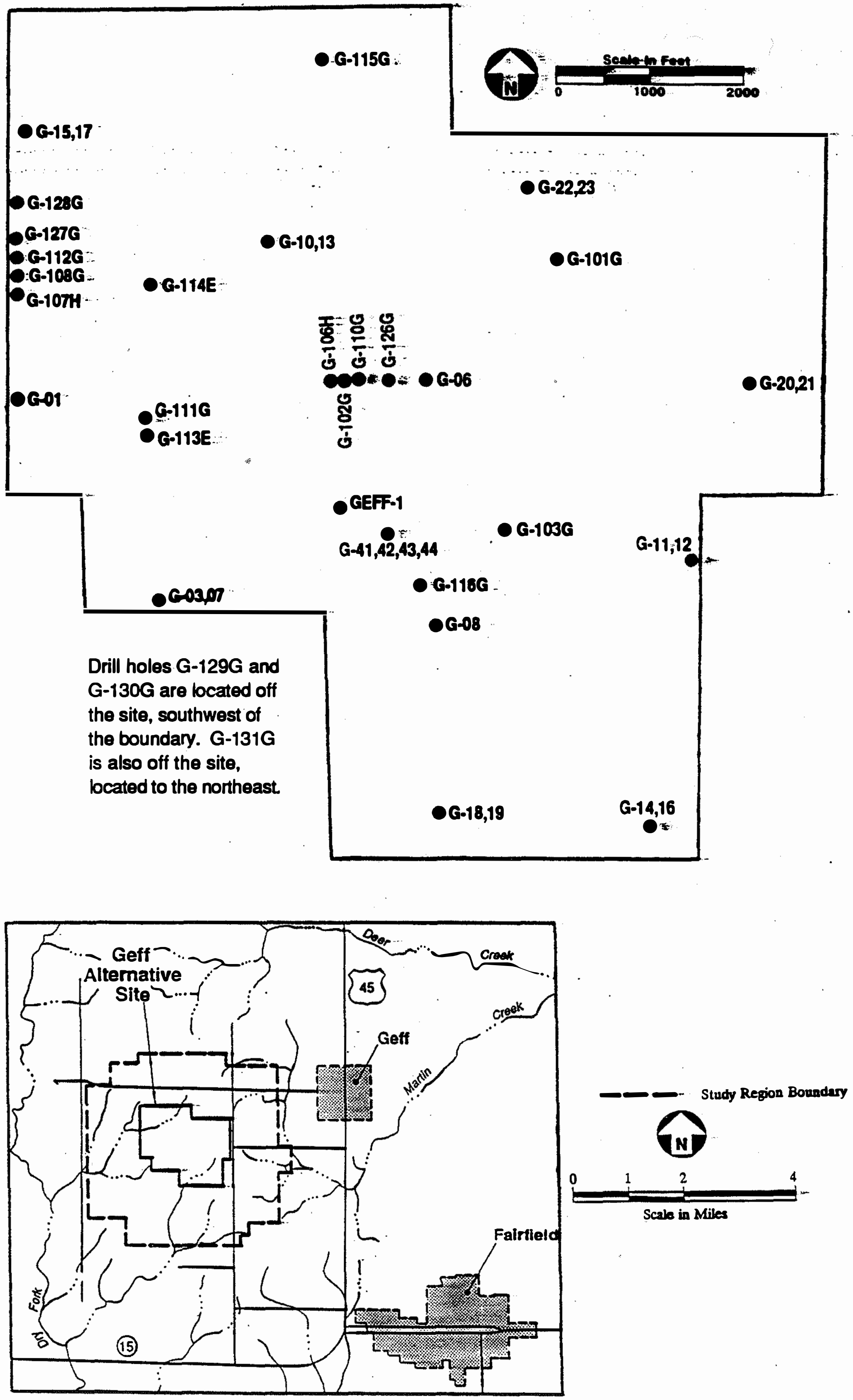


Figure 1. Upper map shows location of drill holes at the Geff Alternative Site used in this study. Lower map shows location of site in the west-central portion of Wayne County.

Surficial

Mudstone/claystone

Shale

Dark gray shale

Black shale

Limestone

Calcareous shale

Sandstone

Conglomeratic sandstone

Interbedded shale and sandstone

Siltstone

Interbedded shale and siltstone

Interbedded siltstone and sandstone

Interbedded sandstone, siltstone, and shale

Coal

T = Terrestrial
M = Marine
M-T = Marine to terrestrial
T-M = Terrestrial to marine

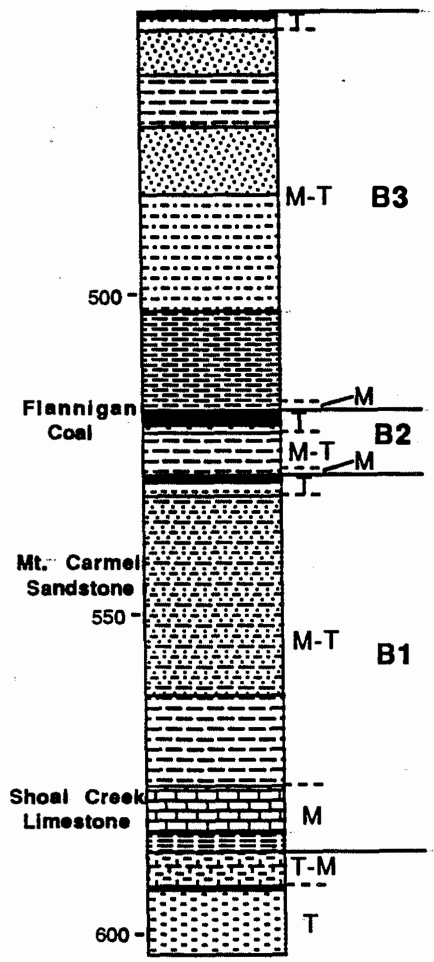
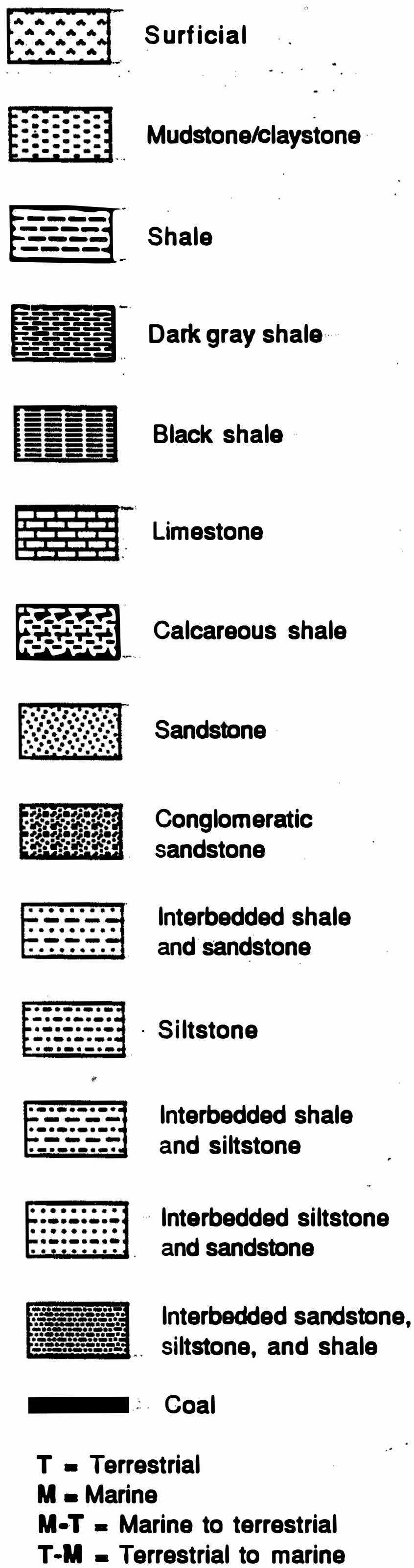


Figure 2. Graphic column of cyclothems B1, B2, and B3 from borehole G-08.



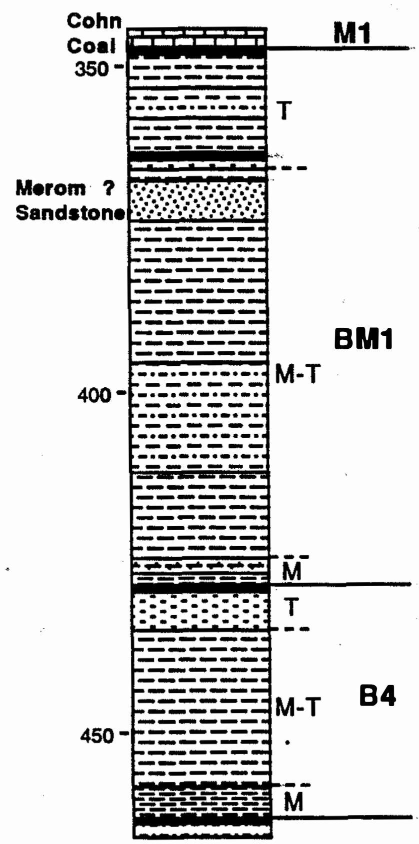
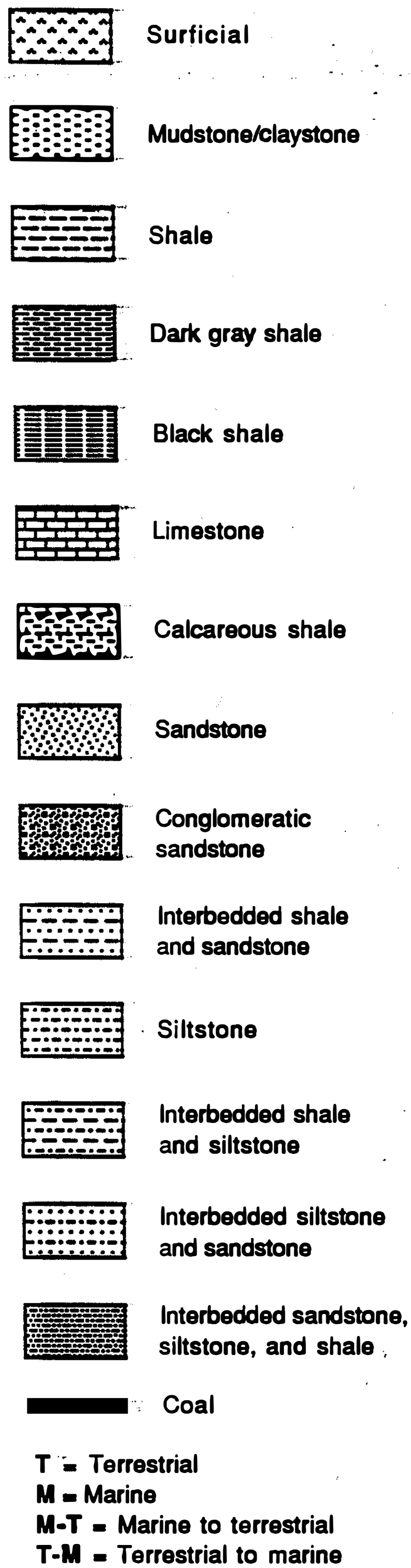


Figure 3. Graphic column of cyclothems B4 and BM1 from borehole G-08.



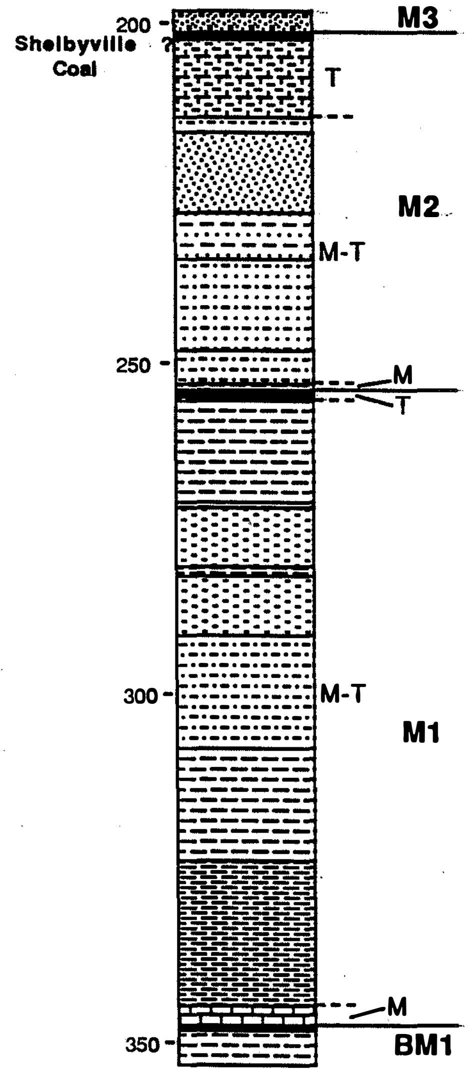
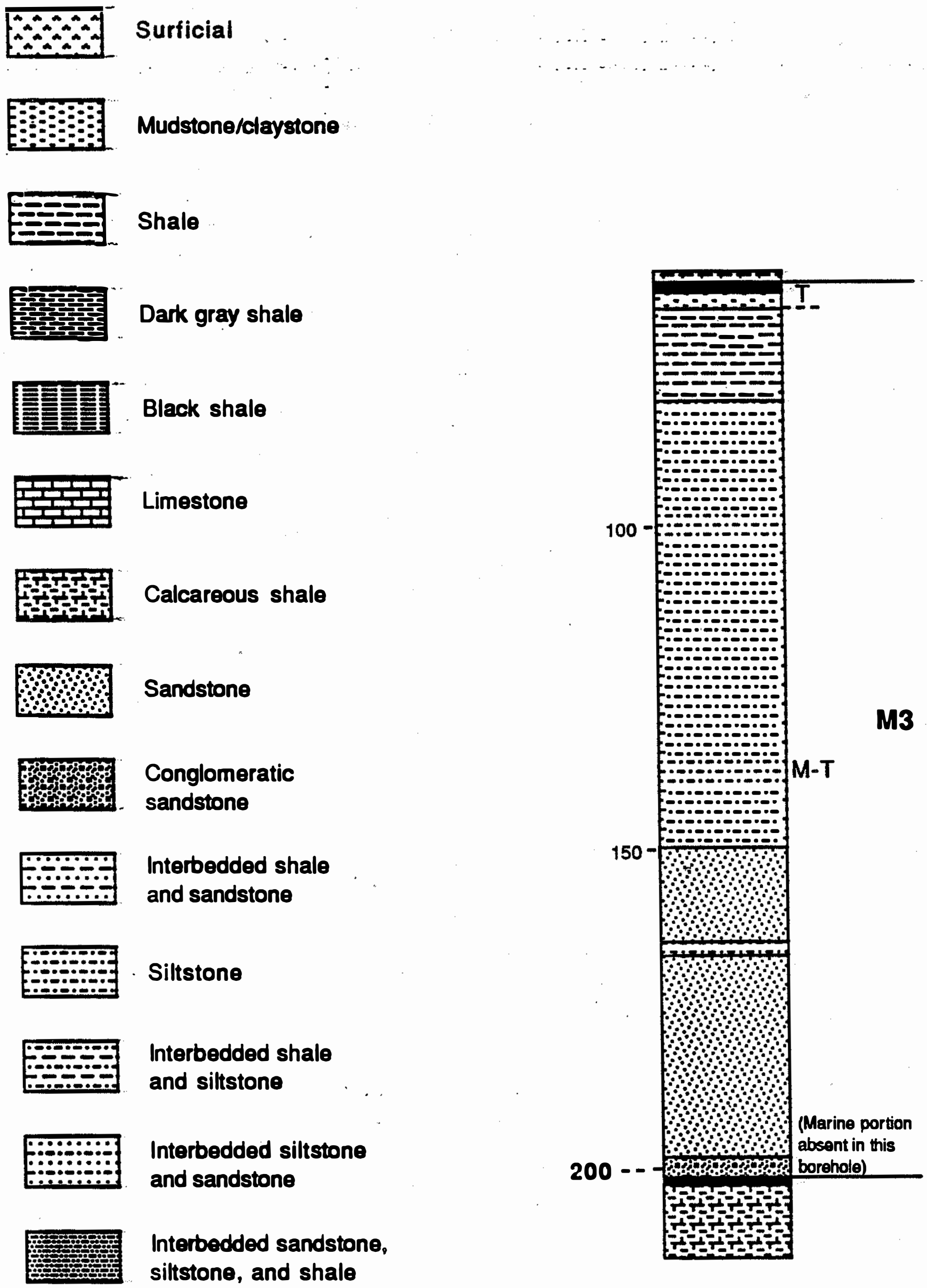
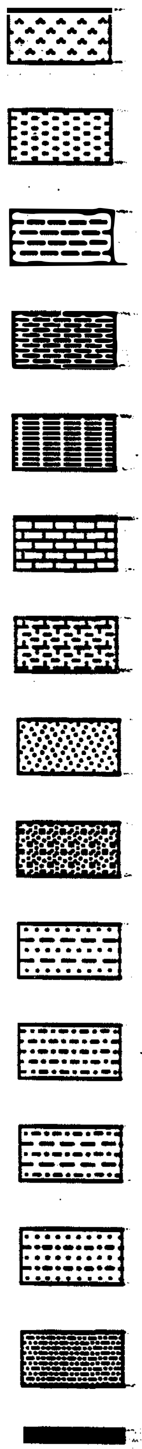


Figure 4. Graphic column of cyclothems M1 and M2 from borehole G-08.



T = Terrestrial
M = Marine
M-T = Marine to terrestrial
T-M = Terrestrial to marine

Figure 5. Graphic column of cyclothem M3 from borehole G-08.



Surficial

Mudstone/claystone

Shale

Dark gray shale

Black shale

Limestone

Calcareous shale

Sandstone

Conglomeratic sandstone

Interbedded shale and sandstone

Siltstone

Interbedded shale and siltstone

Interbedded siltstone and sandstone

Interbedded sandstone, siltstone, and shale

Coal

T = Terrestrial
M = Marine
M-T = Marine to terrestrial
T-M = Terrestrial to marine

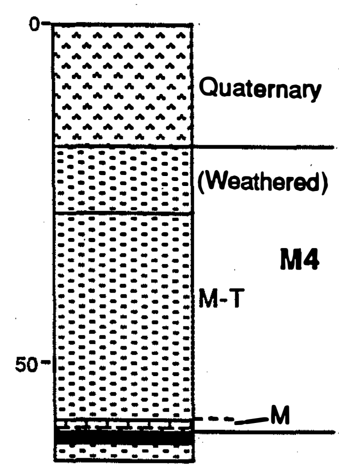


Figure 6. Graphic column of cyclothem M4 from borehole G-08.

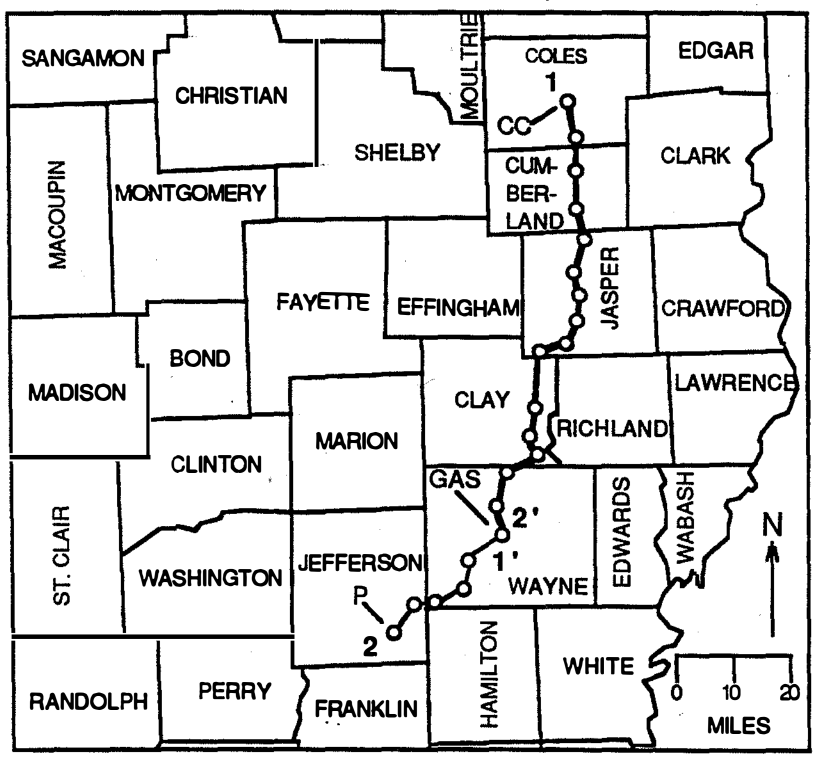


Figure 7. Location map of east-central Illinois showing the north-south cross section (1-1') and the southwest-northeast cross section (2-2'). CC = Charleston core, GAS = Geff Alternative Site, and P = Phillips #1.

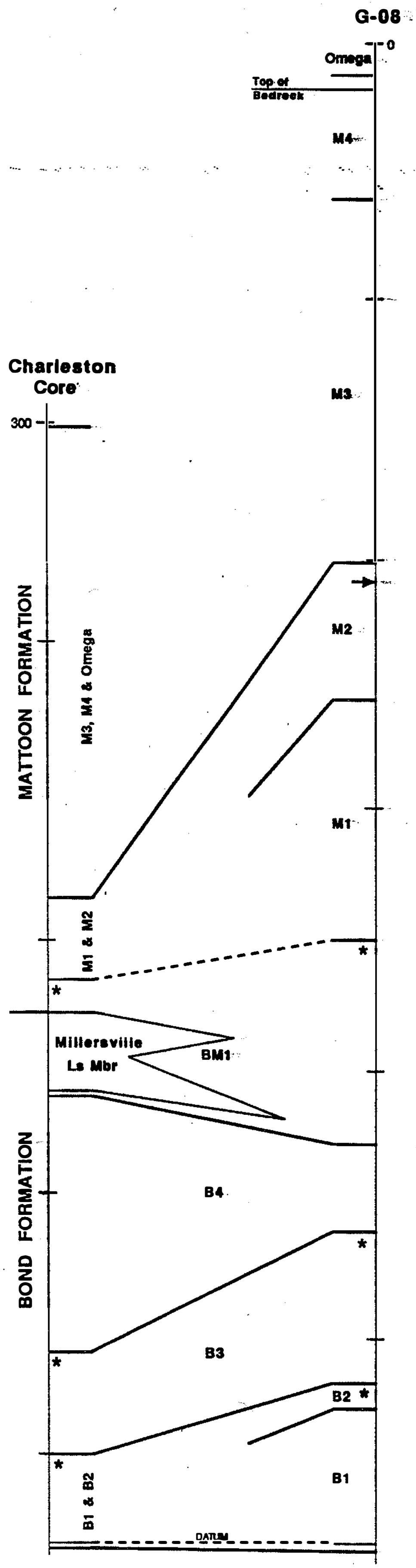


Figure 8. Condensed version of the north-south cross section (Plate 1), using only the end wells. Hachured lines are depth markers spaced every 100 feet. Solid lines indicate correlation of sequences; dashed line indicates biostratigraphic correlation only. Arrow indicates position of the underclay limestone ("Millersville") in cyclothem M2. Astericks indicate positions of coals sampled for palynological analysis. The position of the Omega cyclothem is projected.